What is SLAT?

Seismic Loss Assessment Tool

The Big Question:

What is the cost of seismic activity likely to be, over the lifetime of the building?

What is SLAT?
Seismic Loss Assessment Tool
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What is SLAT?

1. SLAT is the Seismic Loss Assessment Tool

   Current code and practices are highly focused on protecting life: we want to be sure what when a building is hit with a large (though rare) event, it will retain enough integrity for all the occupants to ge out safely.

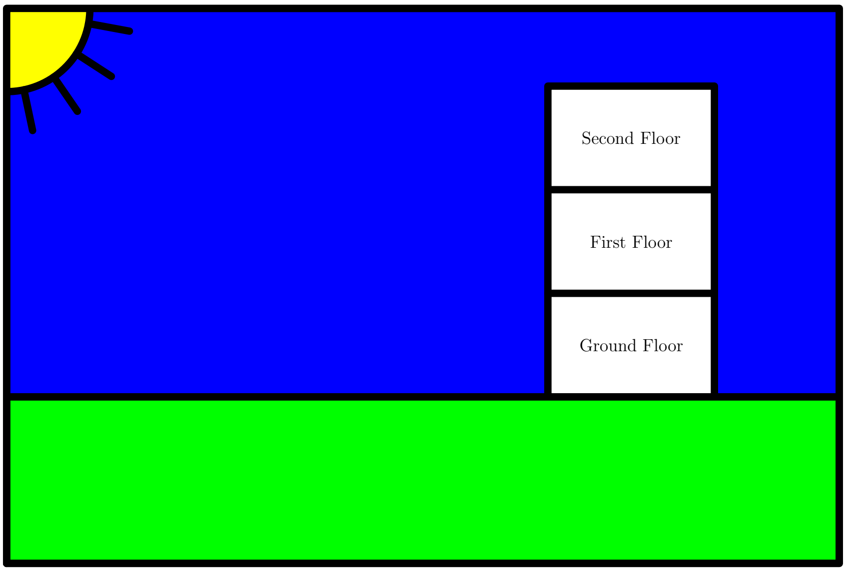
   Throughout it's useful life, however, a building may very well experience a number of smaller events, all of which may cause damage. SLAT attempts to answer...

2. The BIG question:

   The one all your clients will ask..

3. What's it gonna cost me?

A Building

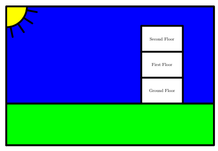


. . . peacefully minding its own business.

2019-03-07

Introduction to SLAT
└How SLAT Sees the World
└A Building

A Building



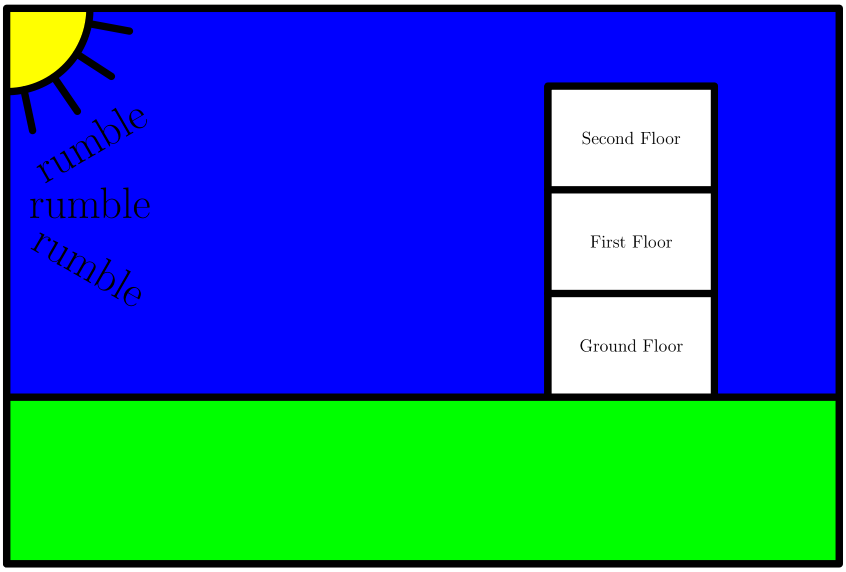
. . . peacefully minding its own business.

Let's consider how SLAT sees the world. SLAT is interested in a particular building, on a particular site.
As far as SLAT is concerned, a building consists of:

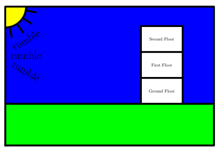
- Structural components
- Non-structural components
- Contents

All of which can be damaged by an earthquake.

A Distant Rumble. . .

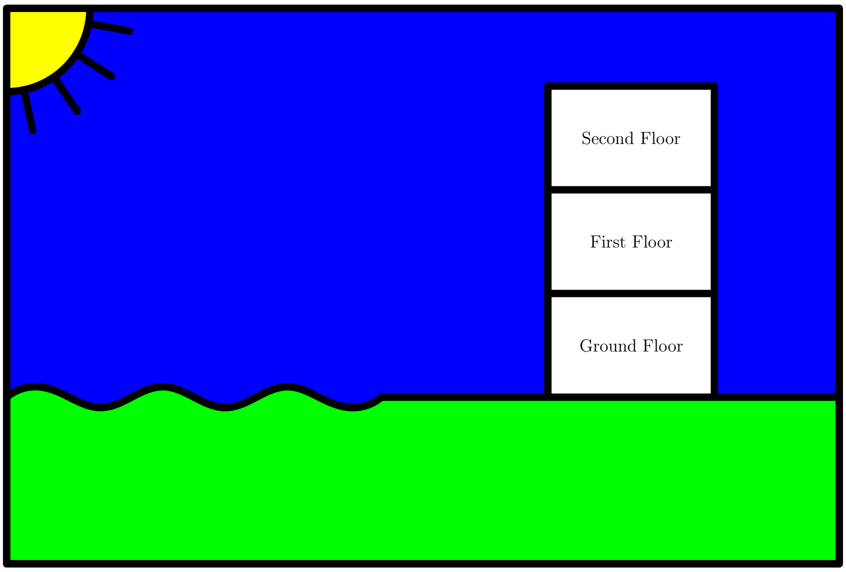


A Distant Rumble. . .



While our building is peacefully minding its own business, far away an earthquake occurs.

The Disturbance Generates Seismic Waves



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Introduction to SLAT
└How SLAT Sees the World
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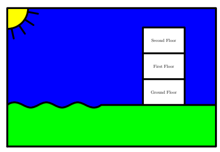
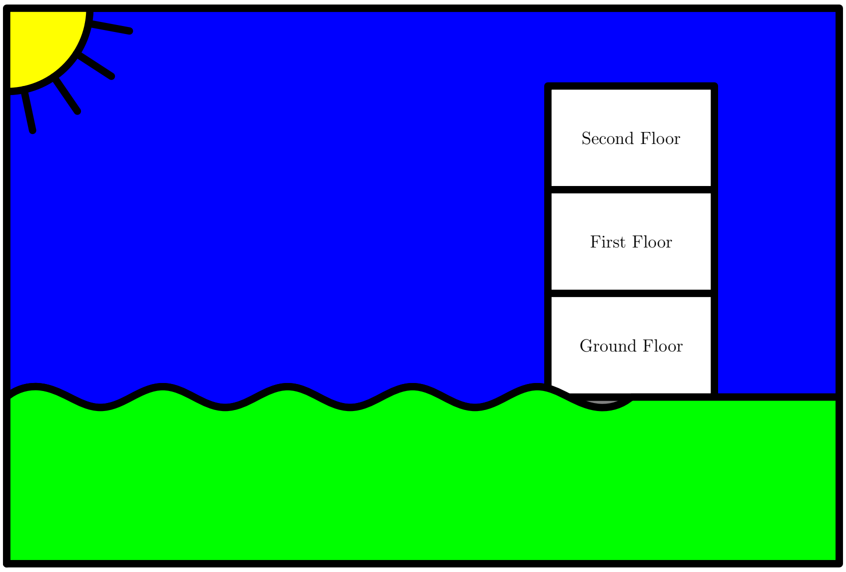
The Disturbance Generates Seismic Waves

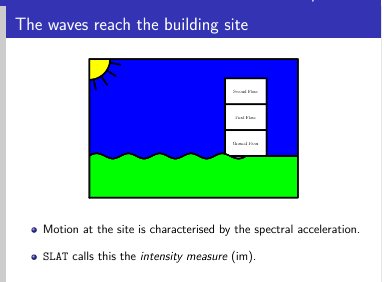


Energy from the earthquake hurtles towards our building as seismic waves!

The waves reach the building site



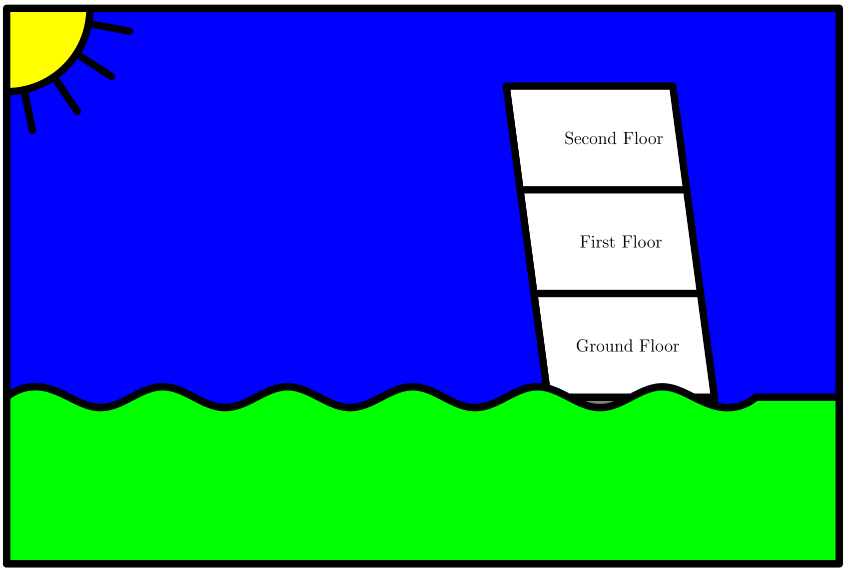
- Motion at the site is characterised by the spectral acceleration.
- SLAT calls this the *intensity measure* (im).



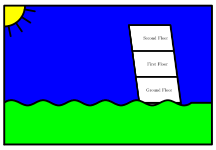
The waves reach the building site!

1. Ground movement at the site is characterise by spectral acceleration
2. SLAT calls this the “intensity measure”.

The building moves



The building moves

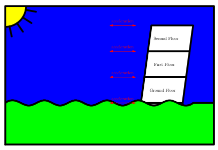


The ground motion is transferred to the building, causing it to move. This motion results in each part of the building being subjected to different forces, which SLAT refers to as *Engineering Demand Parameters*.

Acceleration

Each level (including the base and the roof) experience acceleration.

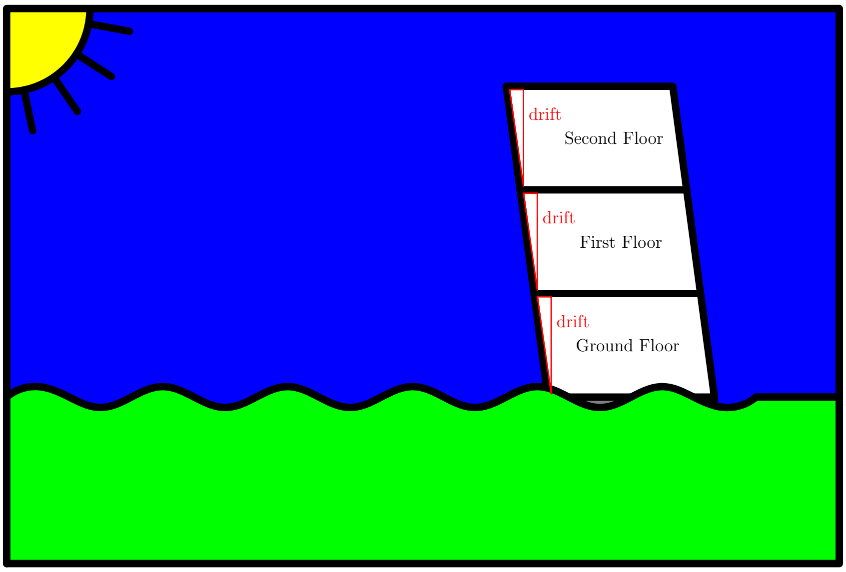
Acceleration



Each level (including the base and the roof) experience acceleration.

Acceleration is one of the engineering demand parameters that SLAT is interested in.

Drift



When the floor and ceiling don't move together, we get inter-story drift.

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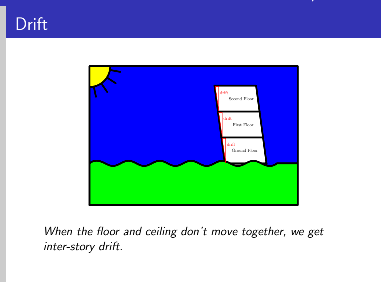
Introduction to SLAT
└How SLAT Sees the World
└Drift



This is the other demand that SLAT is interested in.
Drift and acceleration can both cause damage. Let's look at how SLAT understands this damage.

Damage States

State	Description	Repairs	Demand	Cost
DS1	Small cracks in GIB	Patch	0.0025	$ 35
DS2	Large cracks in GIB	Replace GIB	0.006	$ 55
DS3	Damage to metal frame	Reframe	0.014	$130

Damage States

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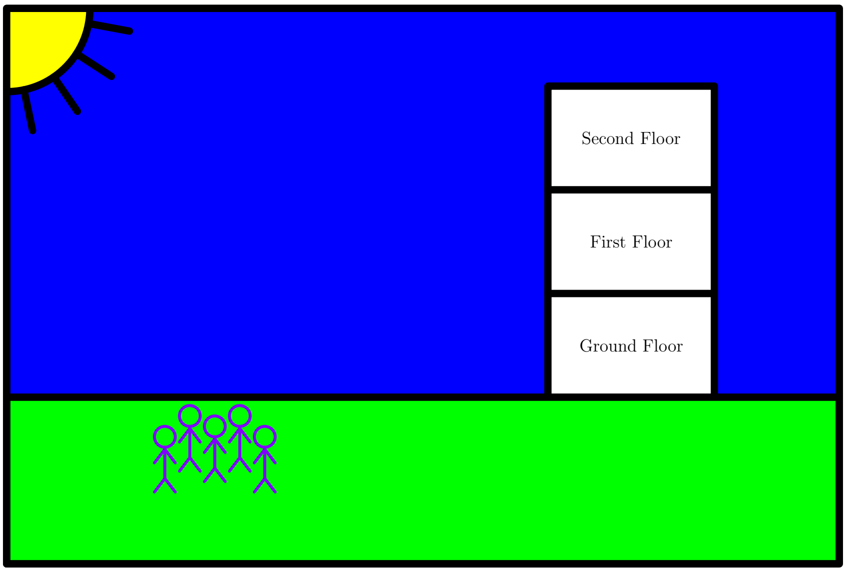
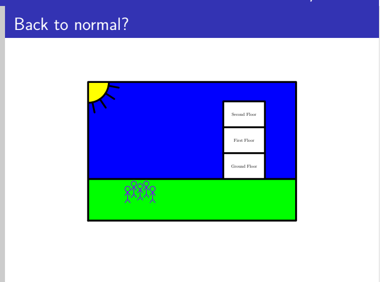
The engineering demands act on the components, possibly damaging them. In the SLAT database, each component is assigned one or more *damage states*. Each damage state specifies:

- A description of the damage and required repairs
- The level of demand at which this damage first occurs
- The cost of the repairs

For example, a full-height interior partition has these damage states... (step through the states)
This is simplified; the demand values and costs are actually probabilistic.

Back to normal?





Let's go back to our building for a moment. The ground has settled down (for the moment), and everyone is safely out, and assembled at the designated assembly point. Yeah, structural engineering! But. . . how much will it cost to repair?

SLAT bases its calculations on:

The Performance-Based Earthquake Engineering (PBEE) framework

From the Pacific Earthquake Engineering Research Center (PEER)

The work of UC Professor Brendon Bradley

$$\lambda(DV)=\int_{IM=0}^{\inf}\int_{EDP=0}^{\inf}\sum_{DS=1}^{n}G(DV|DS)|\Delta G(DS|EDP)||dG(EDP|IM)||d\lambda(IM)|$$

SLAT bases its calculations on:
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So, how does SLAT actually estimate the costs of an earthquake?

1. The calculations are based on the PBEE framework, from PEER
2. and the work of Brendon Bradley
3. which are summarized in the equation.

Being engineers, I'm sure you immediately grasp the significance of this, but I'll go over it for the benefit of any managers who may be here.

The Left-Hand Side

$$\boxed{\lambda(DV)}=\int_{IM=0}^{\inf}\int_{EDP=0}^{\inf}\sum_{DS=1}^{n}G(DV|DS)|\Delta G(DS|EDP)||dG(EDP|IM)||d\lambda(IM)|$$

λ means 'annual rate of exceedence'.

DV is the 'decision variable', which for SLAT is cost.

The Left-Hand Side
$\lambda(DV)=\int_{IM=0}^{\inf}\int_{EDP=0}^{\inf}\sum_{DS=1}^{n}G(DV|DS)|\Delta G(DS|EDP)||dG(EDP|IM)||d\lambda(IM)|$
λ means 'annual rate of exceedence'.
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The left-hand side is, of course, our result.

1. lambda is the annual rate of exceedence, and
2. DV is our 'decision variable'–in this case, cost.

So, we're going to be calculating the number of times a year (on average), we'd expect the cost of repairing a given component to exceed a certain value.

The Outer Integral

$$\lambda(DV)=\int_{IM=0}^{\inf}\boxed{\underbrace{\int_{EDP=0}^{\inf}\sum_{DS=1}^{n}G(DV|DS)|dG(DS|EDP)||dG(EDP|IM)|}_{COST|IM}}|d\lambda(IM)|$$

- Integrating over all possible accelerations
- ..with respect to the rate-of-exceedance

The Outer Integral

$$\lambda(DV)=\int_{IM=0}^{\inf}\boxed{\underbrace{\int_{EDP=0}^{\inf}\sum_{DS=1}^{n}G(DV|DS)|dG(DS|EDP)||dG(EDP|IM)|}_{COST|IM}}|d\lambda(IM)|$$

- Integrating over all possible accelerations
- ..with respect to the rate-of-exceedance

The right-hand side is more complicated. A little, anyway. Let's take it a step at a time.
Look at the outermost integral.

1. This is considering every possible im value, from zero to infinity
2. with respect to the rate-of-exceedence of that value, and integrating the cost of repair given a particular im value.

So, how do we calculate the cost of repair for a given im value?

The Inner Integral

$$\lambda(DV)=\int_{IM=0}^{\text{inf}}\int_{EDP=0}^{\text{inf}}\boxed{\sum_{DS=1}^{n} COST|EDP}\,|dG(EDP|IM)||d\lambda(IM)|$$

- Integrating over all possible demands
- ..with respect to the probability of that demand, given a specific acceleration.

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Introduction to SLAT
└─Calculations
└─The Inner Integral

The Inner Integral

$$\lambda(DV)=\int_{IM=0}^{\text{inf}}\int_{EDP=0}^{\text{inf}}\boxed{\sum_{DS=1}^{n} COST|EDP}\,|dG(EDP|IM)||d\lambda(IM)|$$

- Integrating over all possible demands
- ..with respect to the probability of that demand, given a specific acceleration.

Moving to the inner integration, we're

1. considering all possible demand values,
2. with respect to the probability of getting that value from a given im and integrating the cost of repair given that demand level.

How do we calculate the cost of repair for a given demand?

The Summation

$$\lambda(DV) = \int_{IM=0}^{\inf} \int_{EDP=0}^{\inf} \sum_{DS=1}^{n} \boxed{COST|DS} \Delta G(DS|EDP)||dG(EDP|IM)||d\lambda(IM)|$$

- Summing over all possible damage states
- Cost of damage, weighted by the likelihood of that damage occuring at the given demand

The Summation

$$\lambda(DV) = \int_{IM=0}^{\inf} \int_{EDP=0}^{\inf} \sum_{DS=1}^{n} \boxed{COST|DS} \Delta G(DS|EDP)||dG(EDP|IM)||d\lambda(IM)|$$

- Summing over all possible damage states
- Cost of damage, weighted by the likelihood of that damage occuring at the given demand

Moving in once more, we're at the summation.

1. This is looking at each damage state
2. assessing the cost of the component being in that state, and the probably of it being in that state, given the demand level.

Not So Scary Now

$$\lambda(DV)=\int_{IM=0}^{\inf}\int_{EDP=0}^{\inf}\sum_{DS=1}^{n}G(DV|DS)|\Delta G(DS|EDP)||dG(EDP|IM)||d\lambda(IM)|$$

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Introduction to SLAT
└Calculations
└Not So Scary Now

Not So Scary Now

$$\lambda(DV)=\int_{IM=0}^{\inf}\int_{EDP=0}^{\inf}\sum_{DS=1}^{n}G(DV|DS)|\Delta G(DS|EDP)||dG(EDP|IM)||d\lambda(IM)|$$

Now, the full equation doesn't seem so bad, does it?
Let's look at it again, piece-by-piece, and identify the information we need for the calculation.

Hazard Curve

$$\boxed{\lambda(DV) = \int_{IM=0}^{\inf} \int_{EDP=0}^{\inf} \sum_{DS=1}^{n} G(DV|DS)|\Delta G(DS|EDP)||dG(EDP|IM)|}|d\lambda(IM)|$$

- Annual rate-of-exceedence of IM
- Use NZS 1170 to generate the *hazard curve*.

Hazard Curve

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- Annual rate-of-exceedence of IM
- Use NZS 1170 to generate the *hazard curve*.

Again working from the outside in, the first thing we need to know is

1. the annual rate of exceedence for a given IM value.
2. We can get this for our site using the process outlined in NZS 1170.

Demand Curves

$$\boxed{\lambda(DV) = \int_{IM=0}^{\inf} \int_{EDP=0}^{\inf} \sum_{DS=1}^{n} G(DV|DS)|\Delta G(DS|EDP)|} |dG(EDP|IM)| \boxed{d\lambda(IM)|}$$

- Probability curve of demand given IM
- Results of structural analysis

Demand Curves

$\lambda(DV) = \int_{IM=0}^{\inf} \int_{EDP=0}^{\inf} \sum_{DS=1}^{n} G(DV|DS)|\Delta G(DS|EDP)| |dG(EDP|IM)| d\lambda(IM)|$

- Probability curve of demand given IM
- Results of structural analysis

Next, we need to know the probability the demand will exceed a specified value, given an im value.

1. This is the *demand probability curve*
2. It will come from your structural analysis.

Fragility Function

$$\boxed{\lambda(DV)=\int_{IM=0}^{\inf}\int_{EDP=0}^{\inf}\sum_{DS=1}^{n} G(DV|DS)}|\Delta G(DS|EDP)|\boxed{|dG(EDP|IM)||d\lambda(IM)|}$$

- Probability of each damage state given demand ('fragility curve').
- Stored in the `SLAT` component database

Fragility Function
$\lambda(DV)=\int_{IM=0}^{\inf}\int_{EDP=0}^{\inf}\sum_{DS=1}^{n} G(DV|DS)|\Delta G(DS|EDP)||dG(EDP|IM)||d\lambda(IM)|$
- Probability of each damage state given demand ('fragility curve').
- Stored in the SLAT component database

1. Similarly, we need to know the probability of suffering each damage state, for a given demand value. This is the 'fragility curve' for the component.
2. This data is in `SLAT`'s *component database*.

Cost Function

$$\lambda(DV) = \int_{IM=0}^{\inf} \int_{EDP=0}^{\inf} \sum_{DS=1}^{n} G(DV|DS)|\Delta G(DS|EDP)||dG(EDP|IM)||d\lambda(IM)|$$

- Probability cost exceeding a given value, for each damage state (‘cost function’)
- Also stored in the `SLAT` component database

Cost Function

$$\lambda(DV) = \int_{IM=0}^{\inf} \int_{EDP=0}^{\inf} \sum_{DS=1}^{n} G(DV|DS)|\Delta G(DS|EDP)||dG(EDP|IM)||d\lambda(IM)|$$

- Probability cost exceeding a given value, for each damage state (‘cost function’)
- Also stored in the SLAT component database

1. . . . and we need to know how likely the cost is to exceed a given value, for each damage state.
2. Also in the component database.

Required Data

- Hazard curve
- Demand Curves
- Component Fragility Curves
- Component Cost Functions
- Components in the building
- Mapping of Components to Demands

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1. Hazard Curve :: from NZS 1170
2. Demand Curves :: from structural analysis; more on that in a minute
3. Fragility Curves and Cost Functions :: SLAT component database
4. Components in the building :: based on building design and use
5. Mapping :: which demands affect a component depend on where it is, and whether it is sensitive to drift or acceleration

Demand Curves

Where do we get the demand curves?

- Non-linear Response History Analysis
  - Difficult & Time-consuming
  - May not be meaningful in early stages
- Simplified Approach
  - Equivalent Static Analysis
  - Modal Response Spectral Analysis
  - Apply Corrections:
    - Non-linear effects
    - Higher-order effects

Demand Curves
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Where do we get the data for the demand curves?

1. Could do Non-Linear Response History Analysis, but that's...
2. Difficult and time-consuming, and...
3. Might not be worth the effort, especially early in the design phase.
4. Instead, we use a simplifed approach, where we do..
5. Equivalent Static Analysis, and...
6. Modal Response Spectral Analysis, and
7. Apply corrections for
8. Non-linear effects and
9. Higher-order effects

The Corrections

FEMA P-58

"Seismic Performance Assessment of Buildings"

- From ETABS
  - Fundamental Period
  - Height of Each Story
  - Mass
  - Story Drift at design acceleration
  - Story Acceleration at design acceleration

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Introduction to SLAT
└Calculations
└The Corrections

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- From ETABS
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The corrections SLAT applies come from FEMA P-58. We'll feed it data. . .

1. from ETABS:

   (go over line-by-line)

Additional Information:

- Return Period
- Type of frame in each direction
- Constants from ASCE/SEI 7-10:

R	Response Modification Coefficient
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R Response Modification Coefficient
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ETABS will provide much of the information we need. You'll need to provide additional information.

Yield Strength

FEMA's simplified approach provides an estimate range for the yield strength:

$$\frac{1.5S_a(T)W}{R/I} \le V_y \le \frac{\Omega_0 S_a(T)W}{R/I}$$

SLAT will do this calculation for you, and offer the middle of the range as a default value.

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SLAT will do this calculation for you, and offer the middle of the range as a default value.

Yield strength is used in the FEMA corrections.

FEMA Corrections

The FEMA framework applies the following correction to drift (acceleration is similar):

$$\Delta_i^* = H_{\Delta_i}(S, T_1, h_i, H) \times \Delta_i$$

where:

- S is the strength ratio $\left(\frac{S_a(T_1)W}{V_y}\right)$.
- T_1 is the fundamental period
- h_i is the height above ground of level i
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This is the basic form of the corrections described by FEMA. Yield strength is used to calculate the strength ratio, S.

FEMA Corrections

$H_{\Delta_i}(S, T_1, h_i, H)$ is computed from:

$$ln(H_{\Delta_i}) = a_0 + a_1 T_1 + a_2 S + a_3 \frac{h_{i+1}}{H} + a_4 (\frac{h_{i+1}}{H})^2 + a_5 (\frac{h_{i+1}}{H})^3$$

for $S \geq 1, i = 1 to N$.

FEMA Corrections

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for $S \geq 1, i = 1 to N$.

The coefficients a_0 through a_5 come from tables in the FEMA document, based on the number of stories and frame type. The tables are incorporated into SLAT.

Limitations

The FEMA framework makes some assumptions, which may limit its usefulness:

- The framing systems are independent along each axis
- The building is regular in plan and elevation
- Story drift ratios do not exceed 4 times the corresponding yield drift ratio
- Story drifts ratios are limited to 4%
- The building is less than 15 stories tall

  Consult FEMA P-58 for more details.

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1. Framing systems are independent
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5. Less than 15 stories tall
6. Consult P-58 for more details

The Software

Now, you're thinking:

Seismic loss assessment sounds really great!

But when will I find time for all those calculations?

With `SLAT`, you won't have to!

The Software

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Now you're thinking:

1. *Seismic loss assessment sounds really great!*
2. *But when will I find time?*
3. With `SLAT`, you won't have to.

But what is SLAT, *really*?

Seismic Loss Assessment Tool

- `OpenSLAT` :: C++ calculation engine
  - `libslat` :: shared library
  - `pyslat` :: Python bindings
  - `https://github.com/openslat/SLAT`
- `WebSLAT` :: Web interface
  - `https://github.com/openslat/webslat`

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{{{SLAT}}} is the *Seismic Loss Assessment Tool*

1. `OpenSLAT` is the calculation engine, written in C++
2. Available as a shred library
3. ...with Python bindings
4. Hosted on github
5. `WebSLAT` is a web interface to `SLAT`, which we'll be using today.
6. Also on github

Demo

WebSLAT is installed on a virtual machine, which you'll be able to run on your own PC, using VirtualBox.

Let's have a look at it in action.

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Let's have a look at it in action.

Switch over to the demo script.